"Restaurant Serving Robot with Double Line Sensors Following Approach"

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***Abstract* – This report presents an IEEE format analysis of Restaurant Serving Robot with Double Line Sensors Following Approach encompassing its working principle, components, PID (Proportional-Integral-Derivative) controller implementation, software interface, and applications.**

The widespread integration of robots in the dynamic environment of Industry 4.0 has revolutionized human interaction, especially in the service sector. This work focuses on the optimization and development of PID (Proportional Integral Derivative) controller in the context of a restaurant service robot and recognizes the important role of the controller in making it stable and efficient.

The robot service is designed using a two-wire sensor tracking system carefully designed according to the size and needs obtained from market research. To ensure the accuracy of the PID controller, the robot was designed to reference specific system information tables. Using the line reading algorithm supported by two LED array line sensors on the microcontroller, the robot expertly follows the lines marked on the ground while going to and from the table.

This paper explores the optimization of a PID (Proportional-Integral-Derivative) controller in the context of a Restaurant Serving Robot with Double Line Sensors Following Approach. The robot, designed for precise service in a restaurant setting, integrates a carefully crafted two-wire sensor tracking system. The study emphasizes the PID controller's crucial role in achieving stability and efficiency. A mathematical model is developed, and simulation using MATLAB Simulink showcases the PID controller's influence on the robot's performance. The research not only contributes to the discourse on advanced control systems for robots but also highlights the unique implications of PID controller development in the domain of restaurant service robots.

Index Terms - Serving robot; Line following; PWM; PIC18F4550, PID controller.

I. INTRODUCTION

Modern line-following robots, driven by wheel-based mobility, showcase versatility across military, civil, and industrial realms. Enhanced by smart sensors, image processing, and GPS technology. The fusion of advanced technologies amplifies their real-time decision-making capabilities and expands their operational scope.

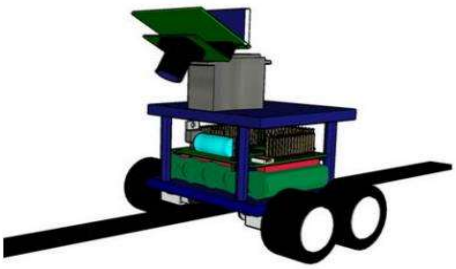

Figure 1-line following Robot.

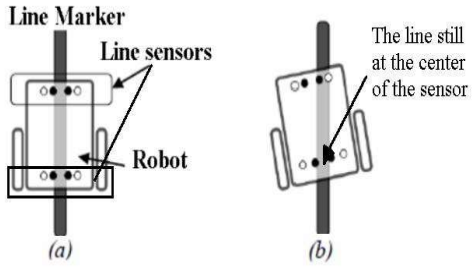

Figure 2-line following Robot(movement).

(a) straight, (b)left offset

Traditional line following robot uses the ON / OFF method, which means when the robot moves to the left of the path, the robot switches off the right motor while the left motor is working normally. This is a very simple robot control method; however, the limitation of this method is that the robot does not move very smoothly. The robot always vibrates to the right and to the left of the path. This vibration affects the movement speed of the robot; the stability is not high; and there is much energy loss. The limitation if using only one-line sensor for this robot is it doesn't detect the angle offset between the robot and the line to be followed. Figure 1(b) is an example for angle offset of the robot and the line to be followed. The line on the floor is still at the centre of the line sensor, but the robot is moving away from the target direction. In order to avoid this problem, Andhra used double-line following approach to solve this problem [1]; however, the double-line technique required the two parallel guiding lines on the floor which is applicable only for that system. We came up with simpler solution by applying two-line sensors which help the robot detecting the angle offset and correcting its movement to the target direction without changing the setup of the line on the floor.

The method for control the moving speed of the robot is by pulse width modulation (PWM). This method controls the rotational speed of the motor based on the average value of the pulse output signal of the controller [1]. This method overcomes the oscillation of the robotic movement, but the limitation of this method is the identification of PWM values to control the speed of two left-right motors while detecting the path of the robot. It is very difficult to find optimal values and poor adaptability to different types of pathways. PID algorithms are widely used in automated control systems. This algorithm attempts to correct the errors between the actual measured values and the desired values by calculating and exporting the correction values from which the operating system is calibrated. The use of PID algorithms helps the control to achieve the desired effect with fast response time and high stability. Thus, applying the PID algorithm in combination with the PWM method in robot control will help the robot to detect the smooth path and move faster and robust to disturbance than the open loop control algorithm. This will be demonstrated in the next section.

In this paper, the authors introduce the mechanical structure of the robot following by a control system combining the PID controller with PWM method. The goal is to design a serving robot that can move steadily to easily bring the product to the selected table position and return quickly and save time, without interruption or collisions during its movement. **[1]**.

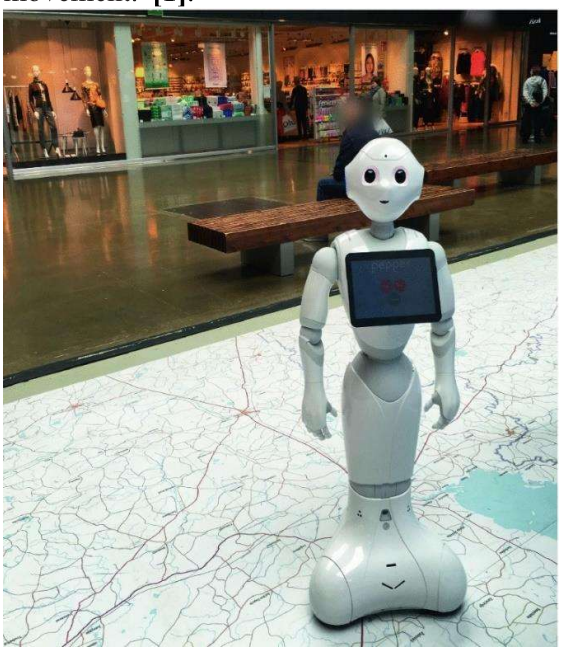

Figure 3-line following Robot.

II. STRUCTURAL DESIGN OF ROBOT

In response to surveys in Da Nang, Vietnam, a team developed a human-shaped robot model for efficient food service. The chosen design, detailed in Figure 4, includes a base for movement, a body with dual trays, and controller panels for operation commands. Motor selection involved calculating power considering friction, leading to the choice of a 12VDC motor with 30W power, 120 rev/min rotation speed, and a weight of 550g, optimizing the robot's ability to carry and deliver food.

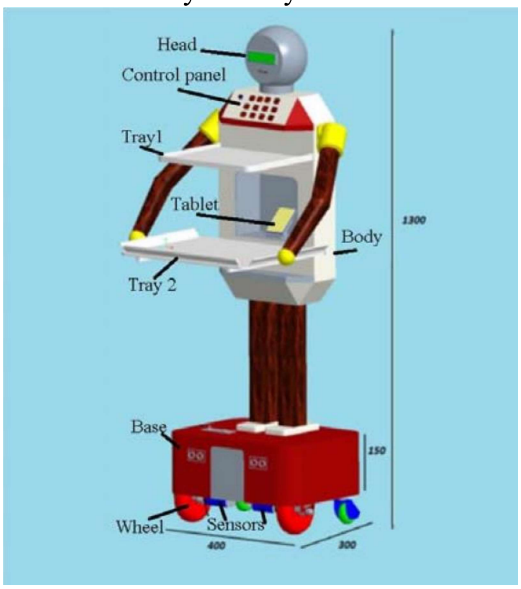

Figure 4 Design of serving robot.

III. CIRCUIT DESIGN FOR SERVING ROBOT

The overall connection of the robot's modules is shown in figure 5. We use two microcontrollers for controlling the robots.

The PIC18F550 is for controlling the motors and operations of the robot while the PIC 16F877A is for selecting table and LCD display control. The power source is the battery 12V-12A which is regulated into 12V-5A using LM2596 chip and 5V-2A using LM2576 chip. The 12V-5A is for driving the motors via two motor drivers while the 5V is for operating the two microcontrollers. The line follower sensor and avoidance sensor are connected to the PIC18F550. The sound module is a speaker that is also connected to PIC18F550. The PIC16F877A is for controlling the mapping data of the tables in the restaurant and navigate the robot to the designed table. The LCD display module is also controlled by PIC16F877A microcontroller. The list of modules of the robot is shown below:

- Central processing unit: Using the Pic18F4550 microcontroller, it performs the function of receiving and processing data from sensor blocks, RF receiver blocks, signal processing blocks for PID control of the robot. Program selection block and display: Select the working mode of taking order or delivering food to table. Select the speaking language of English/Korean/Vietnamese. Show operation status.
- Sensors: Two-line sensors are used for line following and detect the angle offset
- Motor Driver Block: The team designed and created a driver to control a large 30A motor. The driver receives signals from the central processor block for opening and closing as well as sending PWM signal to run the motors.
- Power Unit: We use 12V-12Ah battery power supply, also supply power to the robot.
- Battery Charger: A 12V-20A rechargeable battery circuit that can allow the battery fully charged within 5 hours. Audio block: to communicate with customers by voice in three difference languages.

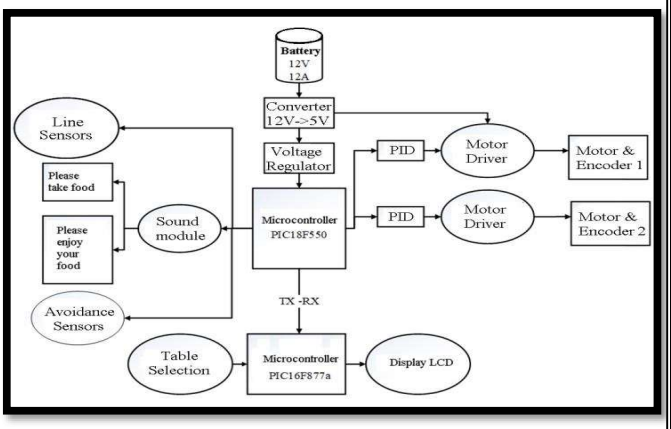

Figure 5- Diagram of robot's circuit system.

The main microcontroller PIC18F550 is responsible for receiving signals from the PIC16F877A microcontroller via the UART port to receive data on the table, client, service or order.

After receiving the data from the line sensor and detect obstacles sensor, the main microcontroller process and help the robot stick to the line to move to the designed table and avoid collisions. PID controller is applied to smoothly move the robot so the food would not slip out the plate. For the convenience of restaurant service, the team also install a set of RF transceiver modules to remotely control the returning to the waiting position after the robot completes its task.**[1]**

IV. CONTROLLER DESIGN

The PID controller is used to drive the PWM of the electric power input to the motors of the robot, the feedback signal is taken from the encoder signal**. [1]**

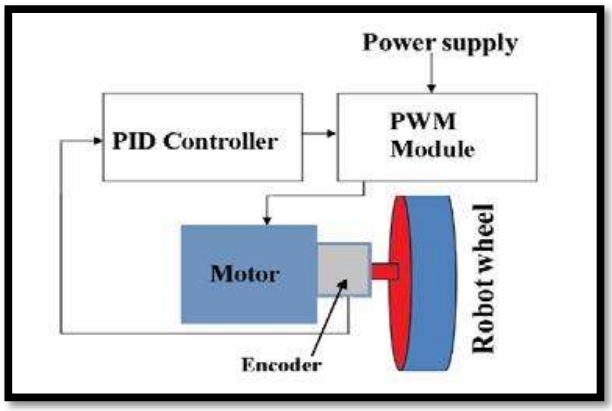

Figure 6 simplified model of robot.

V. PID CONTROLLER PARAMETERS

The transfer function of the angular speed of the robot's motor respected to amount of the voltage input and the moment of inertial of the robot are as follows in (1).

For simulation in MATLAB Simulink software, the following values for the various parameters of DC motor are used : Input voltage Vin=12 v; Motor torque constant Kt = 1.2 Nm/A; Armature Resistance Ra = 0.15Ω ; Armature Inductance La = 0.82 MH ; Geared-Motor Inertia Jm = 0.27 kg.m2, Viscous damping bm = 0.3 N.m.s; EMF constant Kb = 1.2 rad/s/V, Gear ratio n=3, Wheel radius r = 120 mm, robot height h= 1300 mm, robot width b = 300mm, the distance between wheels centers = 400 mm, Equivalent inertia Jacqui =0.27+0.055=0.325 kg.m2 , bequiv = 0.4 N.m.s. The linear output speed for mobile robot is designed at 0.5 m/s, (equal to angular speed ω=V/r = 0.5/ 0.12 = 4.167 rad/s), and the encoder constant Ktac = 2.88 r. **[1]**

VI. PID CONTROLLER IMPLEMENTATION

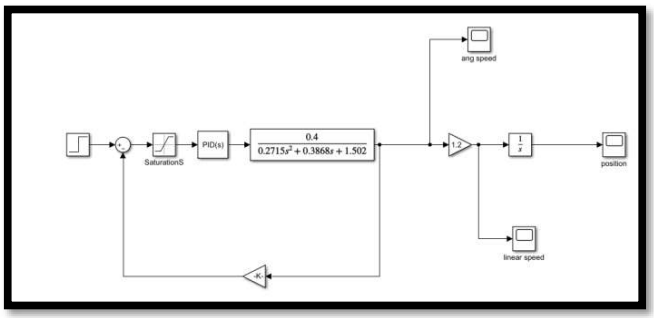

Figure 7 Simulink model for finding parameter for wheel

1. ***Proportional (P) Control:*** Proportional control calculates the difference of the robot speed with the target speed of 0.5 m/s to determine whether the robot is under or over speed, and outputs PWM values to control two motors to help the robot achieving the target speed.
2. ***Integral (I) Control:*** Integral control element adjust the output signal based on accumulated errors over time. The more the robot deviates from the road, the greater the accumulated error. This stage shows how good the robots have been following the target line in the past.
3. ***Derivative(D)Control***:Differential element adjust the output signal based on current errors stage. This indicates the speed at which the robot oscillates back and forth in the path**.[1]**

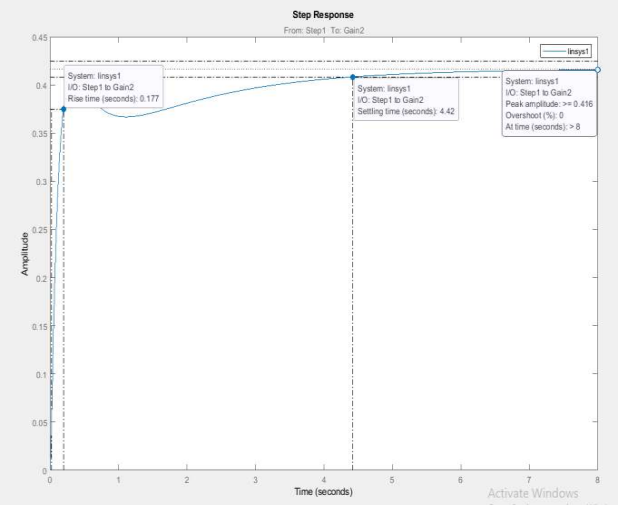

Figure 8- Results of Time Response

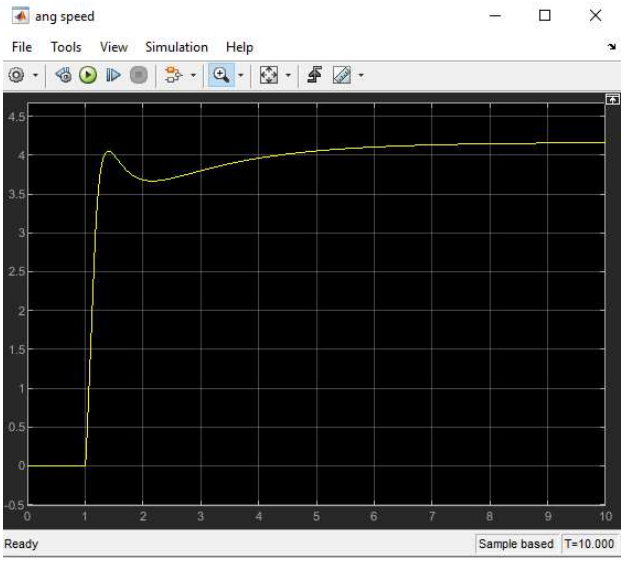

Figure 9 -Angular Speed

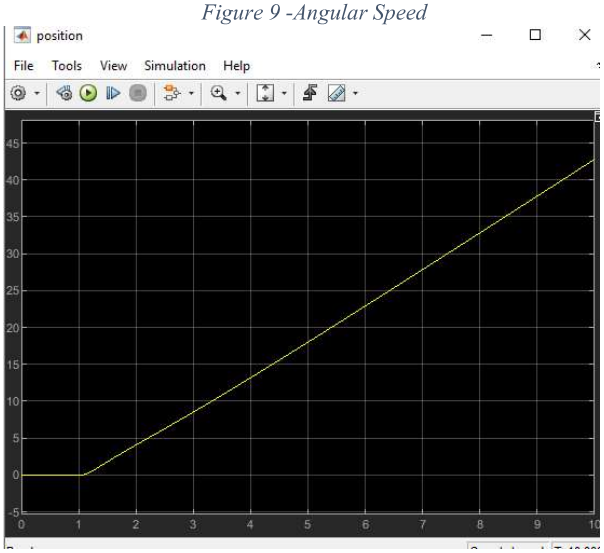

Figure 10- position

VII. IMPLEMENTATION OF PID CONTROLLER WITH TUNING PARAMETERS

The PID controller is tasked with adjusting parameters, such as tire speed, rotation, and position, based on predetermined values. Upon activation, the controller required 5 seconds to stabilize its speed, a duration successfully reduced to 4 seconds.

The implementation involved a Proportional Integral-Derivative (PID) controller, effectively decreasing the initial speed from 5.5 seconds to 4.4 seconds—an accomplishment in optimizing time response. Furthermore, efforts were made to enhance the robot's responsiveness by reducing the time required to approximately 3 seconds for analysing its initial position based on the detected line. These adjustments aimed at improving the efficiency of a restaurant-serving robot.

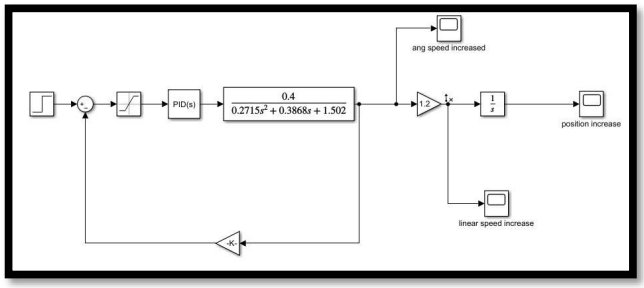

Figure 11 Simulink model for finding parameter for wheel

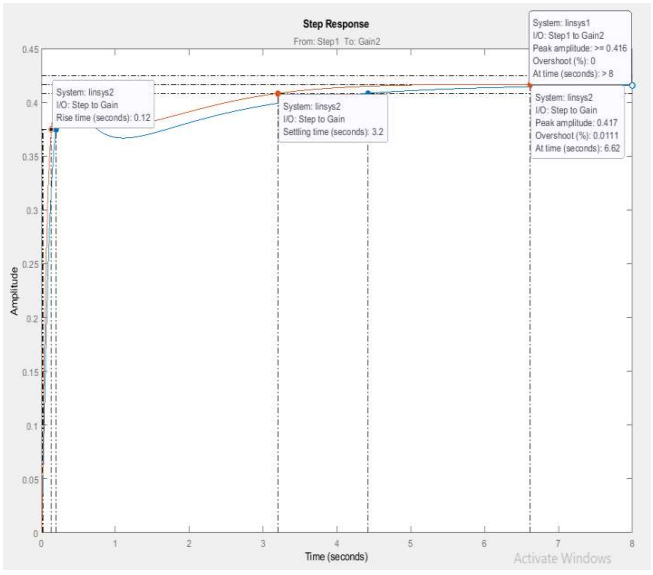

Figure 12-improved time response

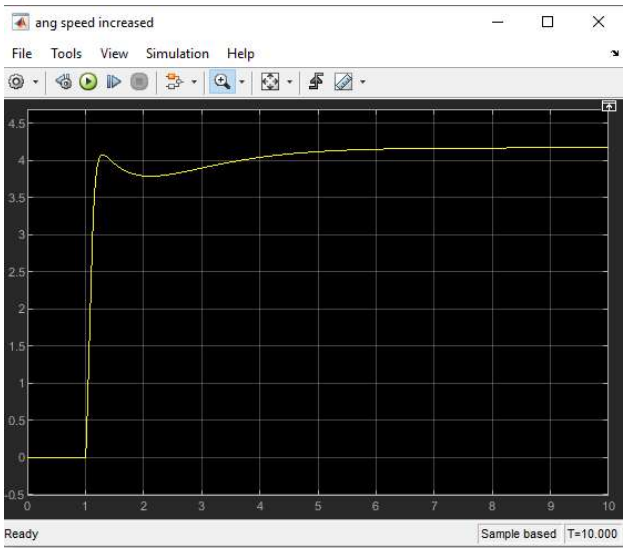

Figure 13-increased angular speed

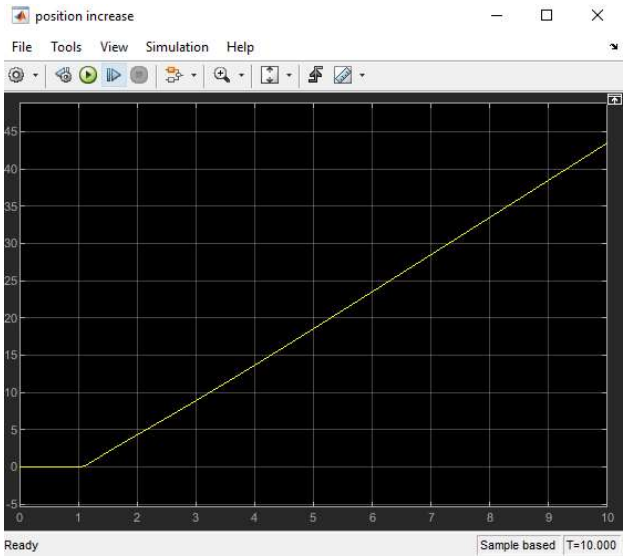

Figure 14- increased position

VIII.COMPARISON OF RELATED WORK

Controller	Tunned	Untuned
Proportional	6.9	5.6
Integral	4.8	3.3
Derivative	3.5	2.25

Table 1- values

LINEAR SPEED	Before tunning	After tunning
Rise time	0.177 s	0.19 s
Settling time	4.42 s	3.2 s
Overshot	0%	0%

Table 2- linear speed comparison

ANGULAR SPEED	Before tunning	After tunning
Rise time	0.19 s	0.13 s
Settling time	5 s	4.18 s
Overshoot	0%	0%

Table 3- Angular speed comparison

IX.APPLICATIONS

The serving robot, featuring a successfully implemented PID controller, is currently undergoing testing at 60s Restaurant in Danang city, Vietnam.

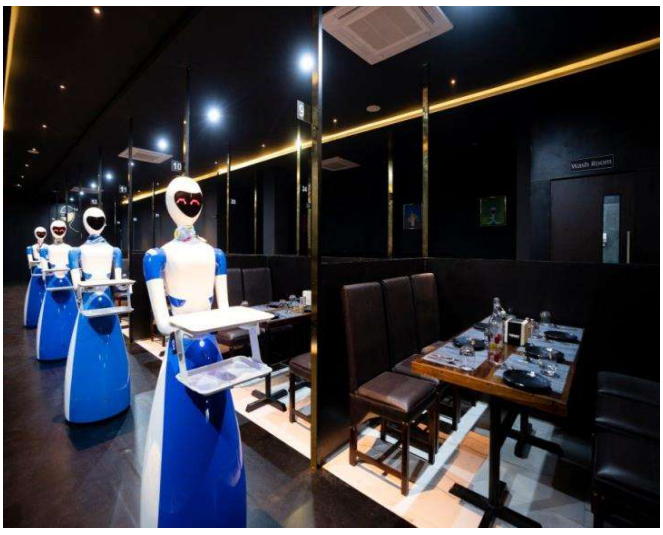

Figure-15-line robots

X.CONCLUSION

In conclusion, this paper has successfully contributed to the enhancement of the serving robot's performance, primarily through the tuning of its PID controller. The meticulous tuning process has resulted in notable improvements, including a reduced settling time, eliminating overshoot, and significantly augmenting both angular and linear speeds. The refined PID parameters have effectively stabilized the robot's position, yielding a more predictable and stable response.

These advancements collectively contribute to a more efficient and reliable serving robot when compared to its previous iterations. The fine-tuned PID controller not only optimizes the robot's precision in navigating and serving but also elevates its overall operational speed. The achieved improvements lay a foundation for future developments in autonomous robotic systems, opening up possibilities for broader applications and increased effectiveness in real-world scenarios. As the research continues to evolve, this work sets the stage for a new standard in the realm of restaurant service robotics.

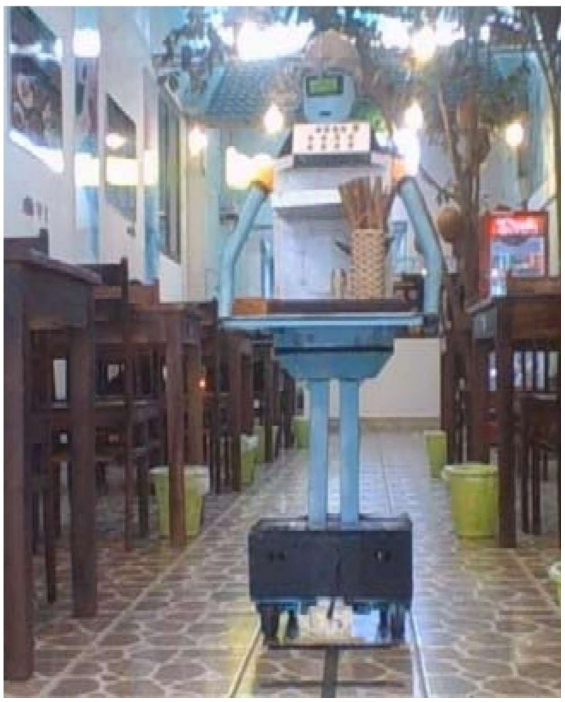

Figure-16- Actual restaurant line serving robot

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